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UNCERTAINTIES in ACOUSTICAL MEASUREMENT and ESTIMATION and THEIR EFFECTS in COMMUNITY NOISE

Summer Meeting TRB ADC-40
Seattle, WA
July 2005

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INTRODUCTION

- Uncertainty effects:
  - Noise measurement is based on imprecise instruments.
  - Noise estimation is based on algorithms that are subject to experimental error.
  - Errors in measurement and errors in estimation can be in the two digit decibel range easily.

BUT

- We assume that we measure what is produced.
- We estimate sound levels at a distance with many implicit assumptions.

ORIGINS OF UNCERTAINTIES

- *Measuring sound pressure*
- *Converting sound pressure to sound pressure level*
- *Determining sound power*
- *Uncertainty in propagation effects*
- *Duration and sampling of the measurement*
- *Microphone location*
- *Measuring sound pressure*
- *Uncertainty issues with metrics*

Measuring sound pressure

- Hydrostatic pressure is a point characteristic, a scalar with magnitude only and no direction.
- Dynamic pressure, a time dependent signal which implies a frequency dependent signal, is indirectly detected by a microphone which disturbs the signal.
  - Pressure hits a compliant object (usually a circular diaphragm)
  - Motion is detected as a change in voltage
    - a supposedly linear relationship
      - between pressure and displacement
      - between voltage and pressure
- A meter, with some uncertainties, reads the voltage and converts it to sound pressure level

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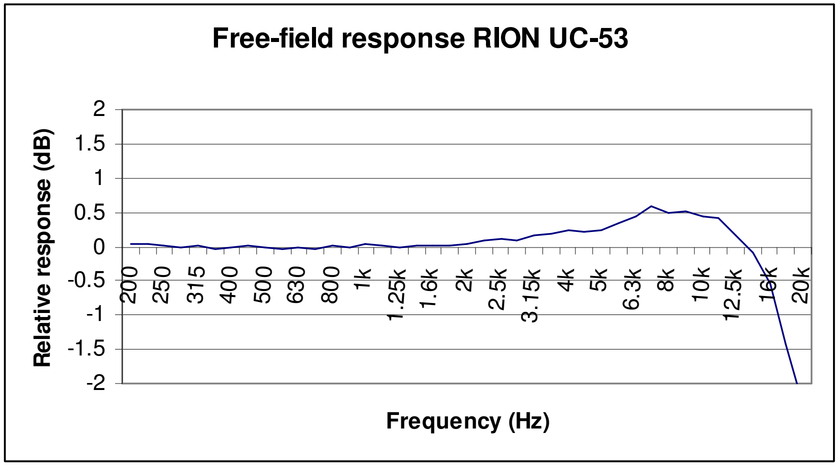
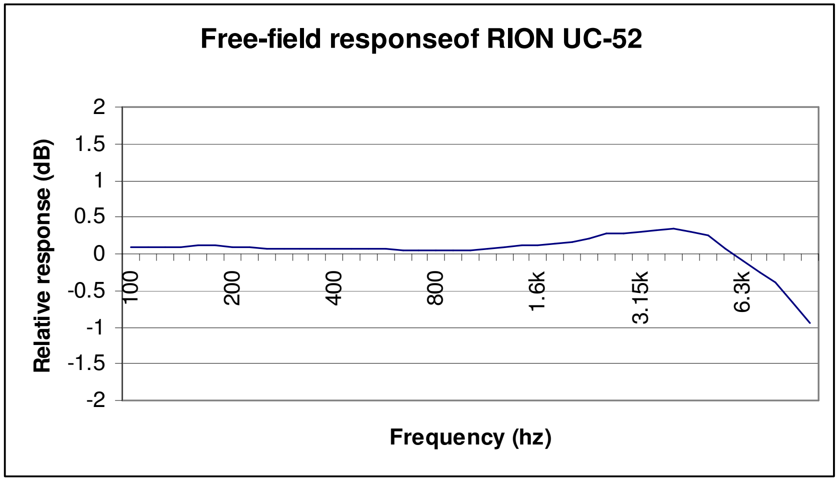
Microphone characteristics

- The linear relationship between pressure and frequency is assumed for a given microphone orientation.
- Class 2 there is no information given for a range greater than 10 kHz. But above 10k & 20 kHz, and even higher, there may be sounds produced.
- Above 20 kHz the effect of sounds on the measurement is unknown for both Classes
- Above 10 kHz there is a good chance one microphone will perform differently than the other.
- Even in the overlapping range, depending on the spectrum of sound measured, results can be off by 1 dB.





Free-field or pressure response

- Omnidirectional microphones
  - frequency response that is symmetric over any circumference perpendicular to the diaphragm axis.
  - frequency response is well known for normal incidence sounds
  - it may be known for grazing incidence sounds
  - even some other angles.
  - For a given physical construction, the relationship between these different responses can be quantified and made part of the microphone documentation.
- Based on construction and grid characteristics, and previously measured data
  - random incidence
  - free-field responses can be derived.
- But the actual measurement is rarely measured in an ideal field.
  - in an anechoic field, often the source is not a point source and the sound is not normal to the diaphragm.
  - in general, the characteristics of the measurement field are not known.
    - Emission
    - Immission

So the frequency response characterized by the microphone calibration laboratory is not that of the measurement.

Omnidirectionality

- Mic omnidirectional w/ respect to a diameter of the diaphragm.
- Sound coming from the rear, depending on the frequency can be easily attenuated by 10 dB or more.
  - The sounds behind the microphone, if of significant level, will influence the reading by some unknown way.
  - So does that suggest to point it straight up?

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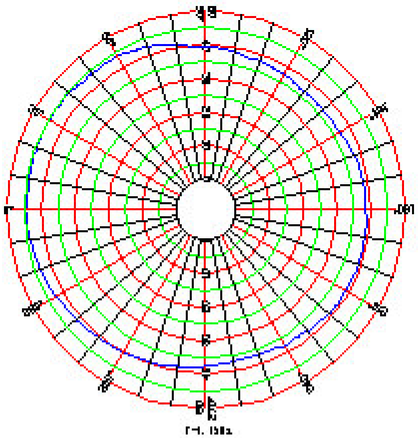
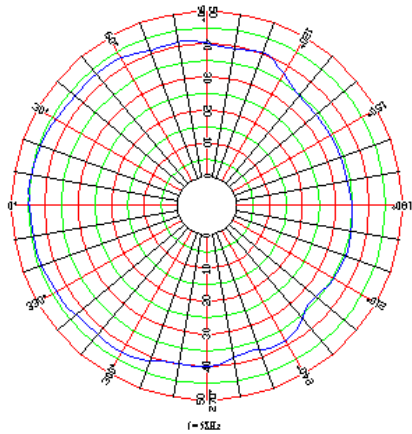
Omnidirectionality

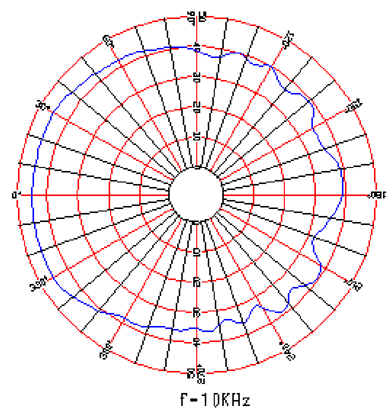


2.5 kHz



5.0 kHz

10.0 kHz



Windscreens

- Insertion Loss (IL) of a windscreen, excluding the effects of wind generated noise, is frequency dependent.
  - Size
  - Porosity
  - Material, fit with the microphone/preamplifier combination
  - Moisture
  - These characteristics may vary with batch or installation.
- Unless either there is little high-frequency sound to measure, or the insertion loss is known, one cannot tell what the windscreen does to the measured sound, by spectrum or even by A-weighted measures.
- Little data on wind attenuation

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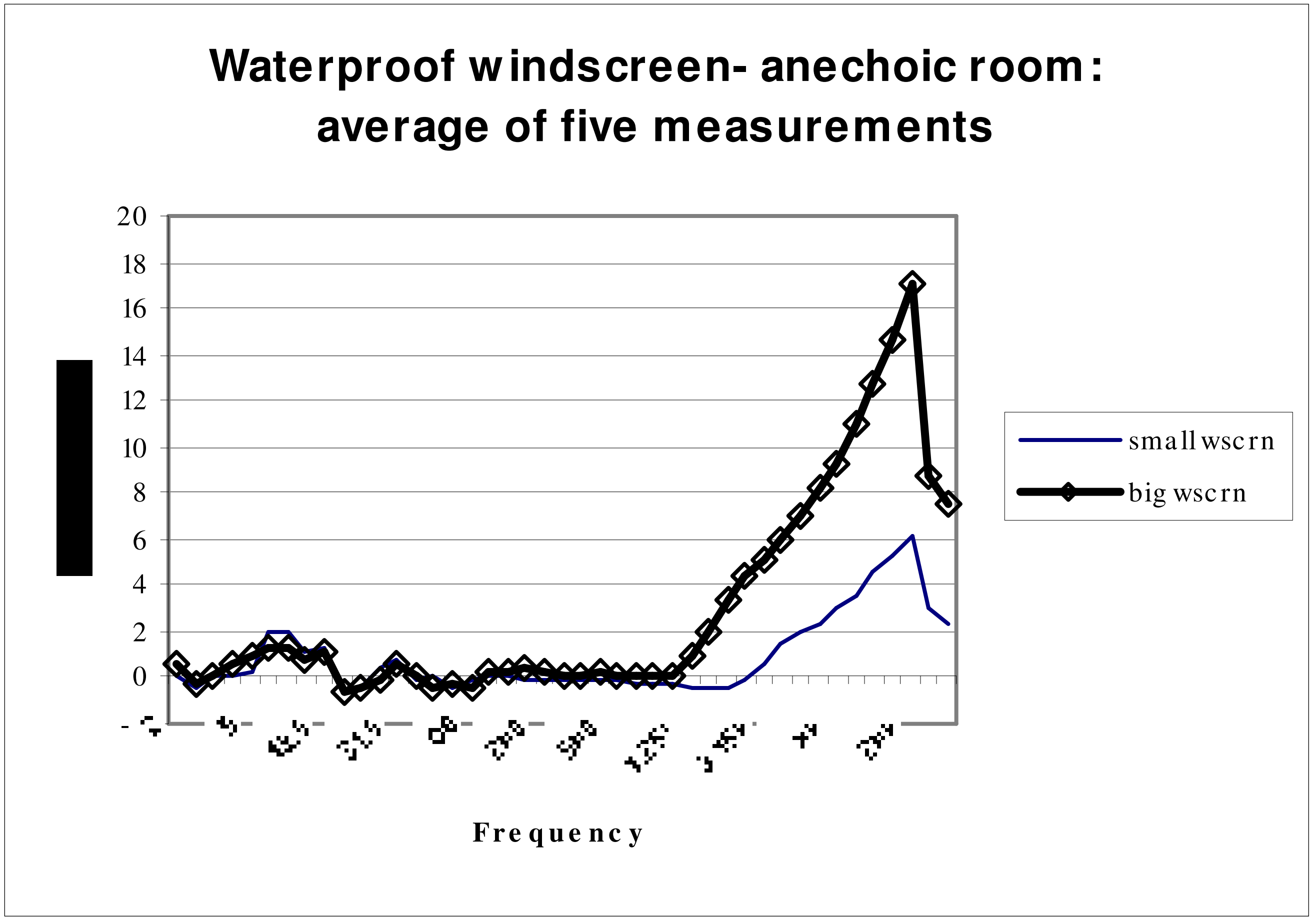
All-weather commercial windscreens



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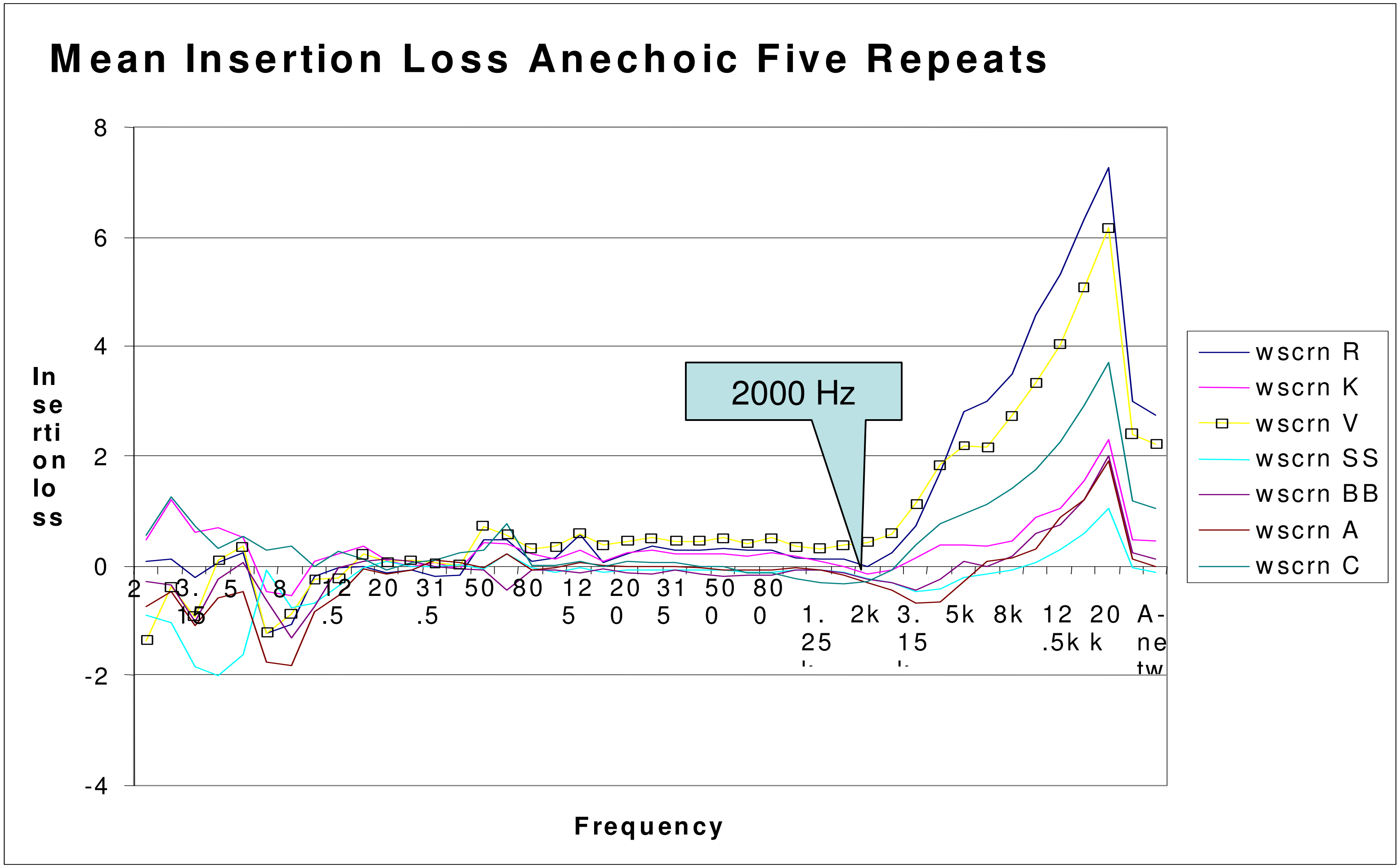
Insertion Loss of Windscreens



Windscreen insertion loss

- In general, the characteristics of a windscreen are not known.
- Few manufacturers provide frequency responses for their windscreens.
- While we can characterize them, few persons are willing to pay for the data.
- As a result, the signal coming into the meter to be further analyzed is often changed by what is in front of the microphone, in an unknown way.

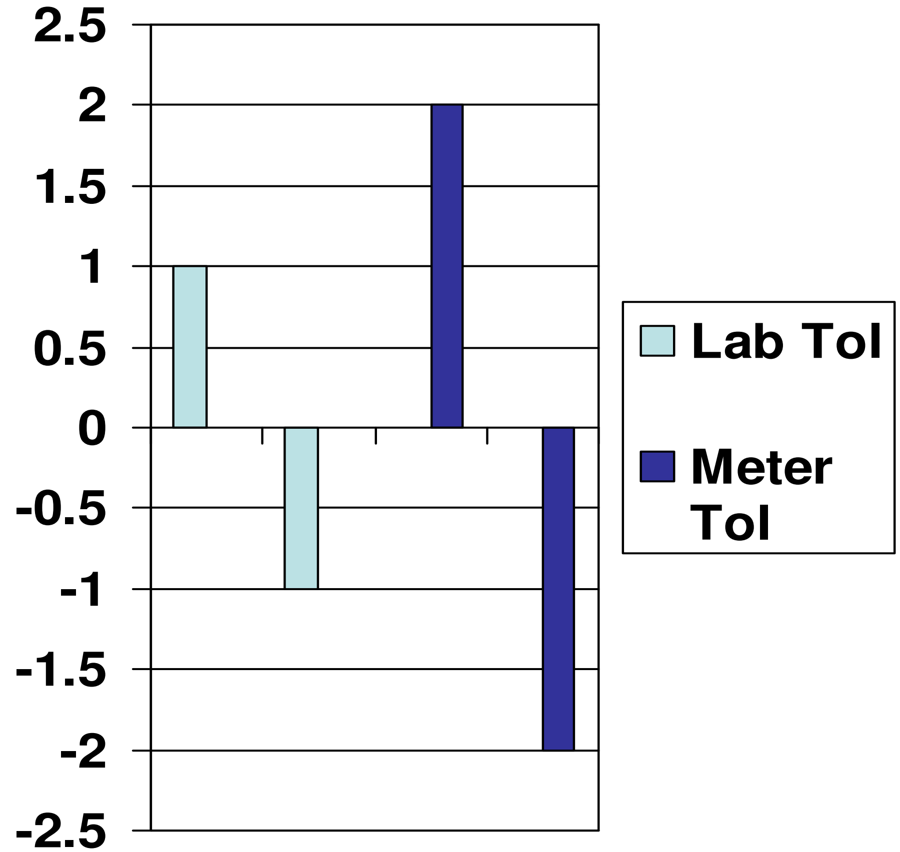
Converting sound pressure to sound pressure level

Sound level meter characteristics

- Microphones + meters = sound level meter.
- The frequency response, linearity, time response, averaging approaches, filter characteristics, etc., are all governed by standards to which they are supposed to meet.
  - International Electrotechnical Commission (IEC)
  - American National Standards Institute (ANSI)
- We often assume these are met by the instrument we use but often they can only be tested in a limited way.
  - Meters w/o removable microphones:
    - checked at discrete frequencies with acoustical excitation.
    - accuracy is less and number of functions tested to comply with standards is fewer.
- Acoustical calibration laboratories are not regulated although some may be accredited.
- The calibration certificate really does not guarantee anything about the performance of a meter. Accreditation is, at present, the only assurance of credibility.

What to do?

- If laboratory reads 0 +/- 1 meter is in tolerance
- If laboratory reads 2 +/- 1 then what?



Field "calibration"

- At best it is a simple sensitivity check at one frequency.
  - Rarely is a calibrator's output exactly what is listed on the label.
  - But that value is often used as the reference level for sensitivity.
- Some calibrators have multi frequency capability
  - No directions on how to adjust sensitivity for more than one frequency.
- Calibrators come in two classes of accuracy:
  - Class 1 is ±0.3
  - Class 2 is ±0.5
- Calibrator error is part of the uncertainty in the measurement for emission AND immission.

Determining sound power

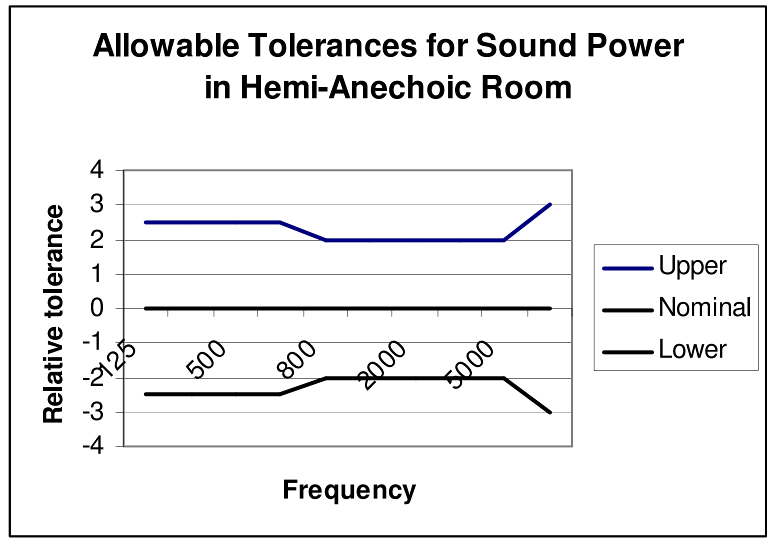
- To make any estimation of sound immission one must know the sound power level of the source.
  - ANSI and ISO
- Most standards deal with small sources
  - fans, electrical generators, snow blowers, heat pumps, etc
  - These can be tested in laboratory environments.
- Bigger, well-defined sources like cooling towers, can be tested in the field in a controlled area.
- But many sources cannot.
  - rock crushers, turbine exhaust stacks, and large ID or FD fans
    - too large to test in the laboratory or in a controlled area
    - have appurtenances that also make noise and are impossible, for geometrical reasons, to test accurately
- But accurate sound power level and directivity are essential for further noise estimation.

Environment

- For large sources, sound power is inferred from sound pressure at a distance (outdoors) (or sound intensity).
  - measure the sound pressure, the sound power is known
    - often, to approximate a point source, you need to be at some distance from the source and the straight line distance can be hard to measure accurately.
    - If you are off by 10% (say 20 m in a 200 m measurement), your uncertainty is about 1 dB.
  - If there is an error in sound power, then there will be a comparable error in sound pressure at a distance.
- For small sources (often not loud enough to matter in the community) and for some large sources like dozers (which really affect the environment) sound power is determined in anechoic rooms.
  - Rooms qualified, to assure a "free-field" environment
  - Places a small (point) source in the center or at the test area and checks to see a 6 dB per doubling of distance over some area around the source.
  - For small sources this approach is adequate
    - expected standard deviation of about 1.0 to 1.5 dB
    - uncertainty of 2.0 to 3.0 dB

Anechoic Room

- There is a rather large uncertainty allowed
  - But the uncertainty assumed is based on a small stable source in this almost “free-field”.
- If the test object is large
  - no point source
  - multiple reflecting surfaces on the source.
  - free field, or even far field, conditions may not be approached.
  - reported uncertainty from the standard may not indeed be related to the uncertainty measured.



Source characteristics

- Complex geometry and complex operating modes
  - stationary air conditioner that cycle on or off
  - graders that moves
- Sound emission a function of load and operating mode.
  - sound power of a dozer
    - Varies with kW
    - Even for a stationary operating position.
- A source can translate, like a vehicle, or rotate, like a grader, or do both, like a loader.
  - The idealized work cycle is often not met in the field
  - A 10 dB difference in Idle-Max-Idle (IMI) measurements and loaded measurements is common.
  - If the source is moving the directivity and the distance can vary significantly with time.
  - Work cycles per Society of Automotive Engineers standards (e.g. SAE-J88) are meant to categorize the source in some standard way. The disparity between the standard work cycle and a real work cycle, which may cover an area of 800 m2 is sufficient to put little value in data obtained for these tests when using it for determination of immission.

Source characteristics.. Cont.

- The temporal nature of sources can be a very big issue.
  - Measuring traffic on a "typical weekday" may, in fact not be representative at all if there is no typical day. And the only way to know if one day is representative of another is to measure all or most of them and chose those that are representative.
- If a source operation is cyclical, like an HVAC unit, then the metric for maximum, or average, may be representative or conservative, or too liberal description of the condition needed.

Uncertainty in propagation effects

The uncertainty in sound power determination will be exactly the uncertainty in sound pressure estimation *if the predictions are done with no additional added uncertainty*.

Algorithms

- For a point source
  - Lp = Lw-20*log10(distance) + Constant + Attenuation
  - Attenuation is a frequency dependent set of numbers that is derived from equations
    - ground effects
    - atmospheric absorption
    - thermal gradients
    - Buildings
    - barriers or berms
    - Wind
    - Foliage
- Algorithms are based on experimental data and can be quite complex.
  - Scatter
  - Non-linearities
  - Measurement error
- Algorithms contribute their own uncertainty.

Precipitation, wind, temperature gradients, temperature

- Measuring in rain or snow is usually not a good idea, but is always done in permanently mounted outdoor monitors.
  - Any studies of the attenuation of precipitation.?
  - The sound of rain, at least, increases the measured sound level as it hits the microphone protection grid.
  - Frozen windscreens can cause significant change in measured frequency response often unknown to the operator
- Wind at a point is temporally variable in speed, direction
- Air temperature is more static and varies, usually slowly, as a function of elevation
  - nearby thermal radiation
  - other heat sources or sinks (like bodies of water)
  - effect of winds on the moisture in the air.

Weather uncertainties

- According to ISO 1996-2, the estimates in standard deviation vary from about 1.5 dB to 2.0 dB.
- Practically, the situation is much worse.
  - it is virtually impossible to measure gradients of temperature or wind, either instantaneously or for long term averages.
  - At any distance the gradient of anything is usually not known
  - Maybe temp & wind at the surface are known
  - So the equations cannot be applied accurately.
- Two other major factors must be included:
  - effects of the wind on the measurement
  - metric used. LmaxF will be different, and much more variable than LmaxS or Leq(1-hr).

Distance

- Uncertainty in distance in measuring or predicting immission is much less important than for the determination of source emission because the error at large distances is very small.
- Uncertainty in sound power can give very large uncertainties in estimated sound pressure level at far distances.

Foliage and Ground effects

Uncertainty

- the database on attenuation is sparse and contains widely varying values of attenuation
- actual measured data, in the field, is hard to determine.
  - What is the density and geometry of the trees compared to published data?
  - Is the density homogenous?
  - What if the ground consists of mixed properties in varied areas between source and receiver? (e.g.: asphalt, ground, grass, asphalt)
  - How do you know the properties of the ground at the specific site?

- ISO 9613-2 provides guidance for simple, flat, hard ground. The difference between their assumptions and the conditions at the actual site contribute to additional uncertainty.

Barriers

Barrier attenuations are based on theoretical calculations.

- Complex barriers, like double walls, thick walls, or berms, are approximated, usually, from perturbations of the thin, infinite, barrier equations.
- Often, sloped barriers, uneven berms with ground cover, slots, etc. will yield undetermined uncertainties from predictions.

Duration and sampling of the measurement

- Duration of the measurement must be sufficient to characterize the source.
  - ISO 1996-2- a certain number of cycles (or pass-bys) must occur: the number proportional to the accuracy.
  - For example, the uncertainty in Leq as a function of single type of vehicle pass-bys is $10/\sqrt{n}$ per. But this number is different for each metric, and for each traffic mix, since the maximum Lp, at least, is vehicle type dependent.
- If you need to characterize a site over a lengthy time period it is best to measure over that period.
- Engineering judgment is needed then to extrapolate that to another time period.
- The sampling approach must be well thought out. And the method of sampling is very dependent on the metric. ISO 1996-2 recommends that any measurement time exceed at least three cycles.
  - This implies if a daily average is required, a measurement of at least three days is needed.
- If a continuous measurement is not possible, samples within these three cycles must be representative.

Measuring sound pressure

- The uncertainties in measuring for immission is similar to that measuring for emission.

Uncertainty issues with metrics

- The metric is a very large contributor to the overall uncertainty.
- As the measuring time increases, the fluctuation in the metric reduces.
- Sometimes the metric is prescribed and the measuring time (interval) is specified. But if not, the following must be considered.
  - Leq
  - MAX or Peak
  - Ldn
  - L90

Leq

- Variability in Leq depends a great deal on the sources.
- If there is an infrequently occurring cyclical sound, such as low density traffic, the Leq can vary depending on when the measurement is made.
- ISO 1996-2 recommends about 10 minutes measurement to obtain an average. But, an average over a few minutes may not be representative of the worst case because traffic mix may not be such to have the nosiest vehicles contributing.

MAX or Peak

- Using the MAXIMUM implies a time constant and, of course, the value measured will be different, depending on that time constant.
  - For the same sound produced, the reading will be different, depending on FAST or SLOW
- Peak readings, rarely used in community noise ordinances, except when confused with Max, are even a greater variability.
  - For a controlled sound (in a laboratory) the peak sound levels for the same signal can vary from about 1.5 to 3.5, depending on type of meter and frequency (See IEC 61672). So the measurement error added to the variability caused by sampling is reason enough not to use peak.

Ldn

- Ldn is a relatively stable descriptor.
  - it takes a long average yearly (?) or 24 hours.
  - Secondly it contaminates the nighttime average by a 10 dB higher average that gets added to the daytime, reducing wide discrepancies in range.
- One pays for the stability with lack of detail and lack of information that can cause community complaints.

Ln

- How sampled
  - Fast
  - Slow
  - Leq
- How many samples per time?

- This determines statistics, independent of sound level.

Microphone location

- The microphone location is often prescribed by the measurement procedure
  - The larger the distance between the source and the microphone, the less important the location.
  - The orientation of the microphone can have a profound effect, depending on frequency of the source.
  - The Type 1 and Type 2 meters should give significantly different results for a high frequency source
    - *In our experience, for automobile sources, the difference between readings of A-weighted sound level of a calibrated Type 1 and Type 2 is less than 0.5 dB*

CONCLUSIONS: What we know about uncertainty

- If you know it you can determine the effects of the measurement.
  - ISO 1996-2:uncertainty of reproducibility is 1 dB.
  - Other uncertainties, (operations, weather, ambient) are assumed 1 dB.
  - Combined uncertainty is 2.0 dB
  - Expanded uncertainty is ± 4.0 dB.
- At best, it is significant and should be accounted for in developing and enforcing municipal noise ordinances.
- If you don't know it, which is often the case, and can't estimate it you don't know anything about your measurement.
- All uncertainties must be known or estimated and accounted for. All reports should state a confidence interval to inform all readers of the uncertainty in the measurements.
  - However, if you present it to the public they will have no clue what you are talking about!